LOS ALAMOS SCIENCE AND TECHNOLOGY MAGAZINE

JANUARY 2007

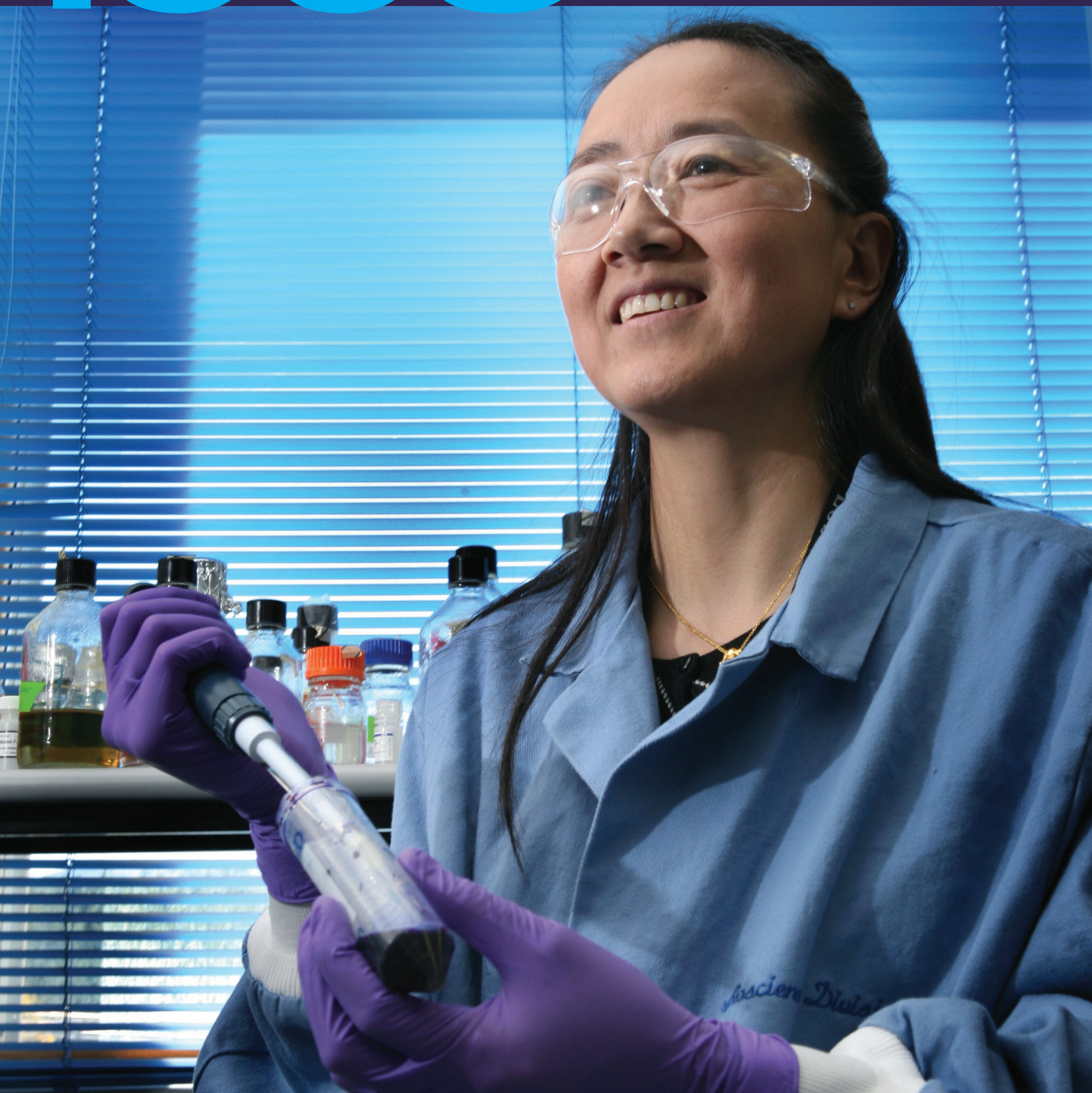
1663

Foiling the Flu Bug

Global Partnerships for Nuclear Energy

Dark Universe Mysteries

The Stockpile Transformed



1663

About our Name: During World War II, all that the outside world knew of Los Alamos and its top-secret laboratory was the mailing address—P. O. Box 1663, Santa Fe, New Mexico. That box number, still part of our address, symbolizes our historic role in the nation's service.

Located on the high mesas of northern New Mexico, Los Alamos National Laboratory was founded in 1943 to build the first atomic bomb. It remains a premier scientific laboratory dedicated to national security in its broadest sense. The Laboratory is operated by Los Alamos National Security, LLC, for the Department of Energy's National Nuclear Security Administration.

About the Cover: The large photo shows Dr. Xiaoyun Lu of the Bioscience Division at Los Alamos, a member of the team of biochemists, theorists, and engineers who are developing a hand-held biochemistry lab for rapidly detecting the influenza virus.

LOS ALAMOS ARCHIVE

FROM THE DIRECTOR

Grand Challenges in Science

This inaugural edition of 1663 *marks a new beginning for Los Alamos National Laboratory, with new management, a new way of doing business, and many new plans for the work ahead. But as the magazine name quietly implies, we are committed to continuing the greatness of this institution. Beginning with the top-secret project to build the first nuclear bomb, this Laboratory has been dedicated to protecting the nation's security in all its many facets—defense, nonproliferation, counterterrorism, energy, environment, and health.*

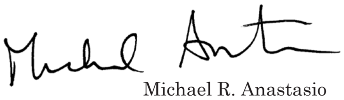
Our unique role is to think ahead, not 5 or 10 years, but 20 and 50 years, and to build a scientific base that can respond to immediate crises as well as prepare for the needs of a rapidly changing world.

This first edition of 1663 *features two long-term nuclear projects that will revive Los Alamos' historic role as a preeminent nuclear physics laboratory.*

One is a global partnership to save the planet from global warming by putting the nuclear genie to good use. In this visionary solution, an advanced nuclear fuel cycle reduces waste while producing fuel for developing nations. Los Alamos scientists have already been forging international relationships that can reduce proliferation risks while making the nuclear option viable.

The other project is a new approach to the nuclear weapons stockpile that will make our nuclear deterrent smaller but more reliable and sustainable. It will also produce a new cadre of nuclear scientists to carry forward the knowledge.

The best and the brightest come to Los Alamos for the opportunity to work on the most compelling problems at the frontiers of science. I have named some of those as Los Alamos Grand Challenges, problems that will be solved more rapidly by a focused effort of our best scientists and the recruitment of new talent. Developing a carbon-free energy cycle, solving the mysteries of dark energy and dark matter, preventing a flu pandemic—all discussed in this edition—are Grand Challenge areas of research that I believe will keep our scientists at the top of their game.



Michael R. Anastasio

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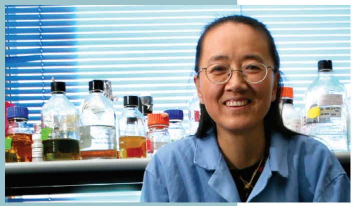

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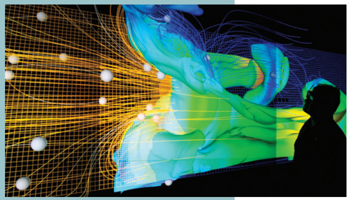

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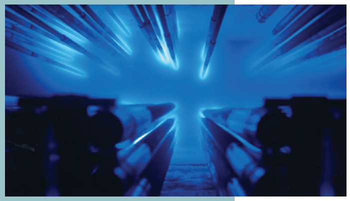

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To Catch a Flu

COLD, FLU, OR SOMETHING WORSE? LOS ALAMOS RESEARCHERS ARE WORKING ON A HOME-USE KIT THAT WOULD GIVE THE ANSWER QUICKLY.

It's a device straight out of *Star Trek*—a hand-held cartridge that can tell you in about an hour if you've come down with the flu. For an individual, that simple piece of information could be the key to a fast recovery. For a community, it could help contain a deadly influenza outbreak.

To Hong Cai, Xiaoyun Lu, David Fox, and their collaborators in the Bioscience Division of Los Alamos National Laboratory, early detection is the key to both fast recovery and the prevention of an epidemic. The team is developing the cartridge—a self-contained biochemistry lab about the size of a deck of cards—to be an inexpensive, portable device that can be used by nearly anyone, whether they are first responders, point-of-care health providers, or homemakers, to detect harmful viruses.

"We call it the dipstick," says Cai, "because it's as easy to use as a dipstick-style home pregnancy test. But it's a really sophisticated little detector."

Most people simply recover from influenza on their own, albeit after a few miserable days of fever, chills, and muscle aches. But influenza can be exceptionally deadly.

The World Health Organization considers influenza to be one of the foremost biothreats facing the planet. The organization's web site includes references to the influenza outbreak of 1918–1919—the "Spanish" flu. A common influenza virus (there are many influenza viruses) had mutated into a variant to which the human immune system had never been exposed. Once the virus entered the human population, the result was a pandemic, a viral blitzkrieg that killed more than 40 million people worldwide.

A similar situation exists today. The H5N1 avian influenza virus, or bird flu, is infecting and killing birds around the world. As with the Spanish flu virus, our immune system has no experience with H5N1. If the bird flu virus mutates and becomes easily transmissible between humans, the world would likely face another devastating pandemic.

The prototype dipstick will detect not only the H5N1 influenza virus but also others that produce flu-like symptoms, such as respiratory syncytial virus (RSV), the SARS (severe acute respiratory syndrome) virus, and the common cold virus. However, its greatest advantage over current detectors is speed. Pandemics are fueled, in part, by a lack of timely information; the virus spreads before infected persons can be identified and properly quarantined. In today's highly mobile society, early detection is an imperative.

"Eventually, we hope to be able to go from sample collection to results in less than an hour, even in patients who are not fully symptomatic," says David Fox, an Agnew National Security Postdoctoral Fellow

Dr. David Fox, shown with his healthy daughter, is keenly aware of how influenza can spread through simple social interactions. He is part of the Los Alamos team that is developing a rapid, home-use influenza detector.

The Spanish flu of 1918 killed as many as 50 million people. Makeshift infirmaries like the one shown were established everywhere.

PHOTO COURTESY OF THE NATIONAL MUSEUM OF HEALTH AND MEDICINE, ARMED FORCES INSTITUTE OF PATHOLOGY, WASHINGTON, D.C.

The flu is easily spread by sneezing.
PHOTO BY ANDREW DAVIDHAZY, SCHOOL OF PHOTO ARTS AND SCIENCES/RIT.

on the dipstick team. "That would give people an incredible head start for initiating response strategies."

The Laboratory is funding the project through an Exploratory Research Grant. And though the bulk of Los Alamos research is not geared towards family health care, the dipstick is aligned with the Lab's long-standing efforts to combat biothreats.

For example, the Laboratory developed methods to detect *Bacillus anthracis*—the bacterium that produces anthrax—and has designed and run computer simulations that predict the course of an epidemic. Los Alamos is also responsible for databases that gather and organize vast amounts of genomic information about AIDS, hepatitis C, and influenza, information that is used by researchers around the world to identify pathogens and design strategies to thwart them.

"All of this information is being compiled about pathogens," says Bioscience Division Leader Gary Resnick. "We needed a way for first responders and health-care providers to apply that information on a daily basis. The dipstick will do that."

Sensitivity and Simplicity

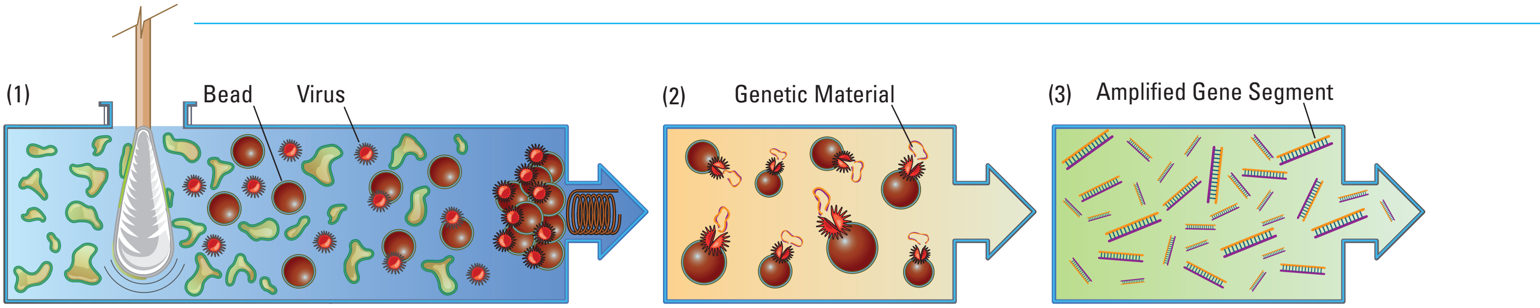
To be effective for home or field use, the dipstick needs to be both sensitive and specific when targeting a small number of virus particles. In Cai's mind, that requirement limited her choices to DNA-based detection methods.

Broadly speaking, there are two ways to detect harmful organisms: protein-based tests or DNA-based tests. Protein-based tests are immunoassays that detect the proteins (antigens or antibodies) that signal the presence of an invading organism. The invader may be friendly (a developing baby—the home pregnancy test is an immunoassay) or unfriendly (a pathogen such as a virus or bacterium). These tests are simple and inexpensive because the proteins are floating freely in samples of urine or blood serum and can be accessed with no special preparation. However, immunoassays lack sensitivity and often fail when there is not enough protein in the sample.

DNA-based tests are very sensitive as well as very specific to targeted organisms. But unlike immunoassays, they require significant sample preparation and processing to obtain the required amount of genetic material. Still, the entire testing process, or protocol, boils down to just four steps. First, researchers *isolate* the organism from the rest of the sample (mucous obtained from a nasal swipe, for example), then they *extract* the organism's genetic material (DNA, or for most viruses, RNA). Next, they *amplify*, or copy repeatedly, a small region of that genetic material (a gene segment) in order to produce enough material to allow the final step, *detection*.

Executing those steps has often required both sophisticated (and expensive) equipment and highly trained personnel. Those two factors relegated DNA identification to either research facilities or well-equipped clinical laboratories.

Determined to change all that, the Los Alamos dipstick team established collaborations with other scientists from the Bioscience Division to develop and/or adopt novel approaches to each of the protocol's four



How It Works: (1) The sample is inserted into the dipstick through the use of a cotton swab. Viruses fall from the swab and stick to protein-coated, magnetic beads, which are then collected by a magnet. The remainder of the sample is washed away. (2) The beads are resuspended in a solution that breaks the viruses open, releasing the genetic material. (3) A novel DNA-amplification scheme creates billions of copies of a targeted gene segment from, for example, virus B (orange). (4) Only those amplified segments can mate to both the label probes (red), which are attached to blue-colored marker beads, and the capture probes (green), which are secured at the virus B detection site. Thus, if a blue spot appears at that site, virus B was present in the sample.

Influenza viruses.

PHOTO COURTESY OF CYNTHIA GOLDSMITH.

steps. From Laboratory scientist John Dunbar's work, the team developed a way to extract genetic material from complex samples. Jian Song and Murray Wolinsky, two bioinformatics experts, helped identify genetic similarities between viruses, which enabled the dipstick team to find gene segments that were unique to the viruses of interest. Amplifying only those segments, instead of those from other organisms, allowed them to separate the wheat from the chaff, so to speak.

Interestingly, the dipstick eliminates the polymerase chain reaction (PCR)—the biologist's standard method of amplifying gene segments—from the protocol. PCR typically relies on a "thermal cycler," a costly piece of equipment that takes the DNA through many time-consuming temperature cycles. Instead, the dipstick uses a cellular enzyme called a helicase to obtain a billion-fold amplification of gene segments. This strategy obviates the need for a thermal cycler since the helicase operates at a single temperature.

"Researchers had developed numerous isothermal amplification methods to amplify gene segments," notes Lu. "The one we chose and refined just matched up nicely with our detection scheme."

That scheme is perhaps the most innovative part of the protocol (see part 4 of illustration). Once amplified, the gene-segment copies are mixed with blue-colored, microscopic beads that are coated with "label probes," which are short, virus-specific pieces of DNA. If one end of the gene segment matches the label probe, the two will bind and the segment will become labeled with a bead. The labeled gene segments then migrate over a detection site that is uniquely coated with millions of short "capture probes." If the free end of the gene segment matches the capture probe, then millions of labeled gene segments become anchored to the site, and a blue spot becomes visible to the eye. If the virus is not in the sample to begin with, no gene segments are amplified and no blue spot appears.

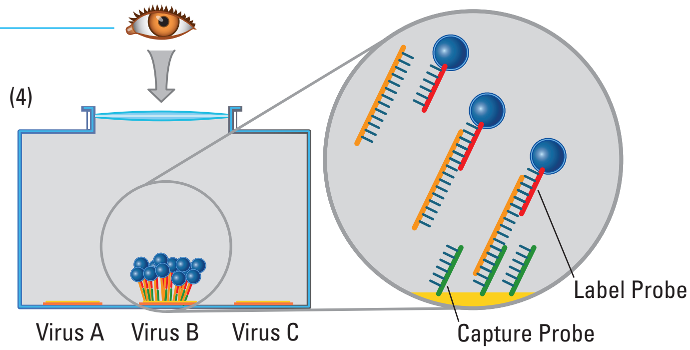
Laboratory tests confirmed that the protocol effectively detects targeted viruses and gives a positive result when as few as 100 virus particles are present.

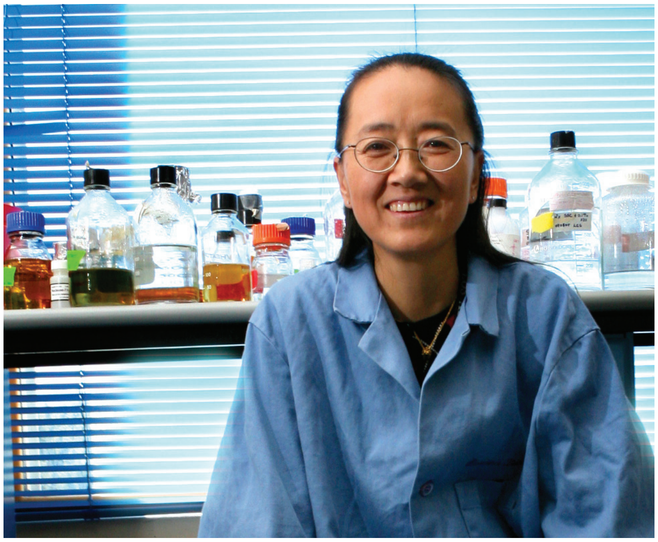
Next, the dipstick needed to be brought out of the laboratory and transformed into an affordable device. Los Alamos is adept at that kind of technology transfer because it has an interdisciplinary approach to problem solving. The dipstick team called on Torsten Staab of the Applied Engineering Technologies Division, and he was able to engineer the world's first hand-held, disposable, DNA-based influenza detector.

Even so, team members were not satisfied to identify viruses alone. They designed the dipstick to test for bacteria as well. The only change to the protocol is in the first step, the one that isolates the organism.

Unfortunately, finding an isolation procedure for bacteria is difficult. "The problem is one of specificity," explains Lu. "Although we can isolate most viruses from the rest of the sample, we can't do the same for all types of bacteria." So the group is focusing on *Bacillus anthracis*, largely to address bioterrorism concerns.

The dipstick has caught the attention of an industrial manufacturer, who hopes to mass-produce the device at a projected retail cost of about $10 per dipstick. If that happens, we can all start thinking about clearing a little shelf space in our medicine cabinets.





Dr. Xiaoyun Lu, a member of the Los Alamos dipstick team, developed the dipstick's detection method.

LOS ALAMOS, A WORLD LEADER IN COMPUTING SINCE THE BEGINNING OF THE DIGITAL REVOLUTION, IS MOUNTING A MAJOR INITIATIVE TO HELP UNRAVEL THE MYSTERIES OF DARK MATTER AND DARK ENERGY.

Shown here are two nearby galaxy clusters that collided about 150 million years ago. The gases from each cluster (red regions imaged with x-rays) were slowed down by collisions and left behind, whereas the massive dark matter components (blue regions imaged through gravitational lensing) are collisionless and therefore passed through each other unimpeded. This separation of dark and ordinary matter is being touted as the first direct evidence of dark matter.

X-RAY: NASA/CXC/CFA/M.MARKEVITCH ET AL.; OPTICAL: NASA/STSCI; MAGELLAN/U.ARIZONA/D.CLOWE ET AL.; LENSING MAP: NASA/STSCI; ESO WFI; MAGELLAN/U.ARIZONA/D.CLOWE ET AL.

LIGHTING UP THE DARK UNIVERSE

For most of the 20th century, everything that cosmologists observed in the heavens confirmed the laws of physics we know on Earth.

But in the background, a crisis has been building. Starting with early (1933) observations of galaxy clusters, evidence has accumulated to suggest that the matter in planets, stars, and interstellar gas—ordinary matter made of neutrons, protons, and electrons—is but a small fraction of the matter in the universe. Most of it appears to be cold and dark, to have no electric charge (making it unable to emit or absorb light), and to collide so infrequently with other matter that it never heats up or cools down.

This "dark" matter is invisible to us, but Newton's laws tell us that it must exist to provide the gravitational force that keeps the fastest stars confined within our own galaxy and the fastest galaxies bound into giant clusters.

Apparently, all the luminous matter we observe is embedded in massive amounts of unknown dark matter in the form of extended halos. That was hard enough to swallow. But things got even stranger.

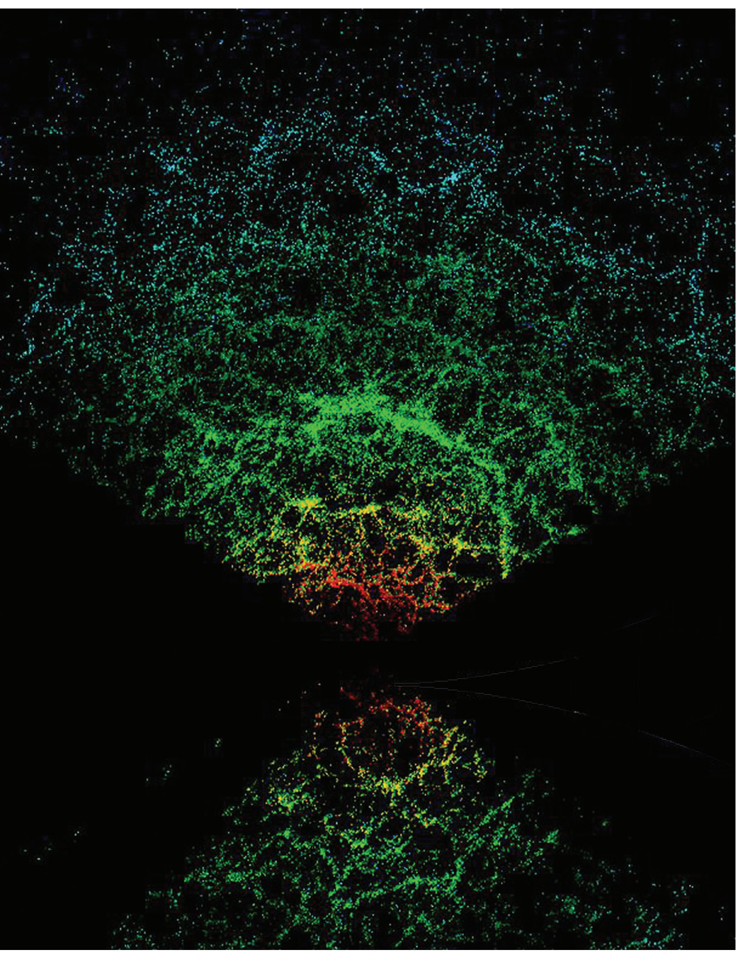


PHOTO COURTESY OF THE SLOAN DIGITAL SKY SURVEY (SDSS.ORG)

A Sloan Digital Sky Survey map of the luminous universe out to a distance of 5 billion light years. We (and the present time) are located at the center between the two pie-shaped regions. Note how galaxies condense into lace-like filaments and walls as time progresses from the outer edges of the map to the center.

In 1998, the search for distant supernovae (exploding stars) revealed that the overall expansion of the universe, which began about 14 billion years ago, is not slowing down as it should under the braking power of gravity.

Instead, the expansion appears to be accelerating under the influence of a mysterious force, dubbed *dark energy*. Over the past eight years, the evidence for dark energy has finally turned the world of physics on its ear. Computer simulations of the dark matter universe, when compared with the latest maps of luminous matter and the latest maps of the cosmic microwave background (the radiation left over from the early universe), indicate that the universe contains an astonishing 74 percent dark energy, 22 percent dark matter, and only 4 percent ordinary matter.

"This is a very stimulating time for physics. Fully 96 percent of the universe seems to be composed of stuff we've never seen directly on Earth!" says Emil Mottola, Los Alamos theorist, who has his own model of dark energy.

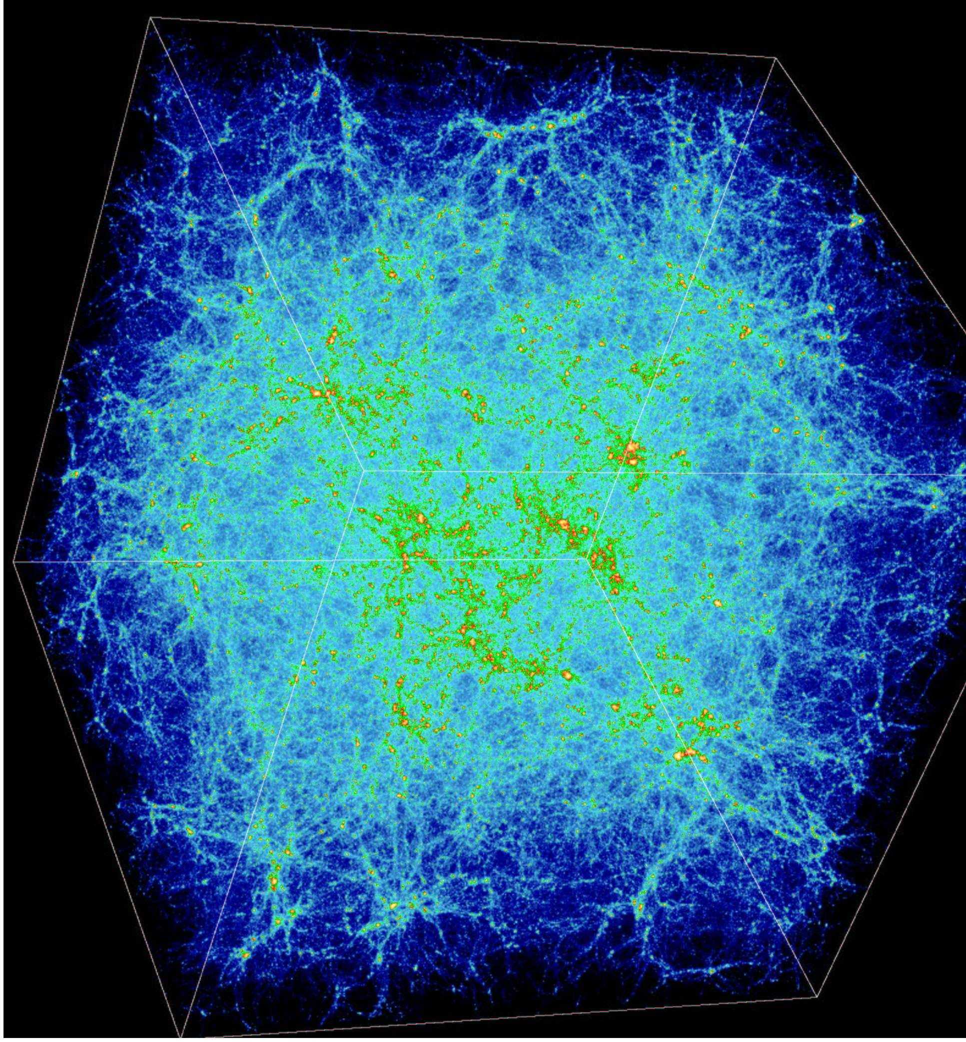
According to the Dark Energy Task Force, a joint committee sponsored by the U.S. Department of Energy, the National Science Foundation, and the National Aeronautics and Space Administration, "[N]othing short of a revolution in our understanding of fundamental physics will be required to achieve a full understanding of cosmic acceleration."

The three agencies have plans for a multi-billion-dollar exploration of the deep universe. By charting its expansion history back to the time when the universe was less than half its present size, the astro-explorers hope to track the ebb and flow of cosmic acceleration and how it has altered the rate at which galaxies merge into clusters, superclusters, and huge lace-like structures of filaments and walls (see the figure at left). If they can discover the true nature of dark energy, they will find out whether Einstein's theory of general relativity, the description of the expanding universe that has held for 75 years, needs to be changed in some fundamental way.

Success will depend on coordinating theory, computation, and the many types of observation planned for the future. Lab Director Mike Anastasio has named the problem a Grand Challenge for Los Alamos, and research scientists at Los Alamos are gearing up for the task by developing close collaborations with large astronomical surveys, including the Sloan Digital Sky Survey at the Sloan telescope in southern New Mexico. The Sloan survey is the largest sky survey ever undertaken.

PHOTO BY JOHN FLOWER

Mike Warren, winner of four Gordon Bell prizes for his high-speed simulation code HOT, is providing catalogs of dark matter halos to many research groups across the country.



Warren's billion-particle simulation showing the typical distribution of dark matter in the universe today. Dark matter density increases from blue to light blue, to yellow, to orange. Ordinary matter condenses into stars and galaxies in the higher-density regions.

Unbounded Acceleration?

The surveys hope to test various theoretical notions of dark energy. The simplest, called the cosmological constant, postulates dark energy as a constant energy density tied to empty space. Its presence is felt as a negative pressure, or repulsive force, opposing the force of gravity and putting a damper on the tendency of matter to clump.

According to the theory, when the universe is young and dense, the dark energy has a very small effect, but as the universe expands, the total amount of dark energy increases to fill the volume, causing the expansion to accelerate faster and faster. In about 100 billion years, this strange energy density causes most of the luminous matter in the star-filled heavens, except for a few galaxies near our own Milky Way, to disappear from our view.

Albert Einstein's theory of general relativity permits empty space to exhibit this bizarre property and, because in 1917 scientists thought the Milky Way was the whole universe, Einstein invoked the cosmological constant to convert his prediction of an expanding universe into a description of a stationary one.

Later, after Edwin Hubble discovered that the universe was indeed expanding, Einstein openly expressed his disdain for the cosmological constant, calling it an ugly thing that should never be realized in nature.

"Today the cosmological constant is back and being used in computer simulations," says Salman Habib, a theorist at Los Alamos. "But it has no natural explanation at the quantum level and brings home the fact that we don't have a consistent quantum theory for gravity." Quantum theories have successfully described three of nature's basic forces (electromagnetic, strong nuclear, and weak nuclear) in terms of a duality between particles and waves. That same approach applied to gravity suggests that an energy density such as the cosmological constant could arise from energy fluctuations in empty space, that is, from particles that pop briefly in and out of existence. However, this approach also predicts a much larger value for the energy density than has been observed—larger by a factor of 3 followed by 121 zeros!

The contradiction has led theorists to posit new ideas of what dark energy might be, including

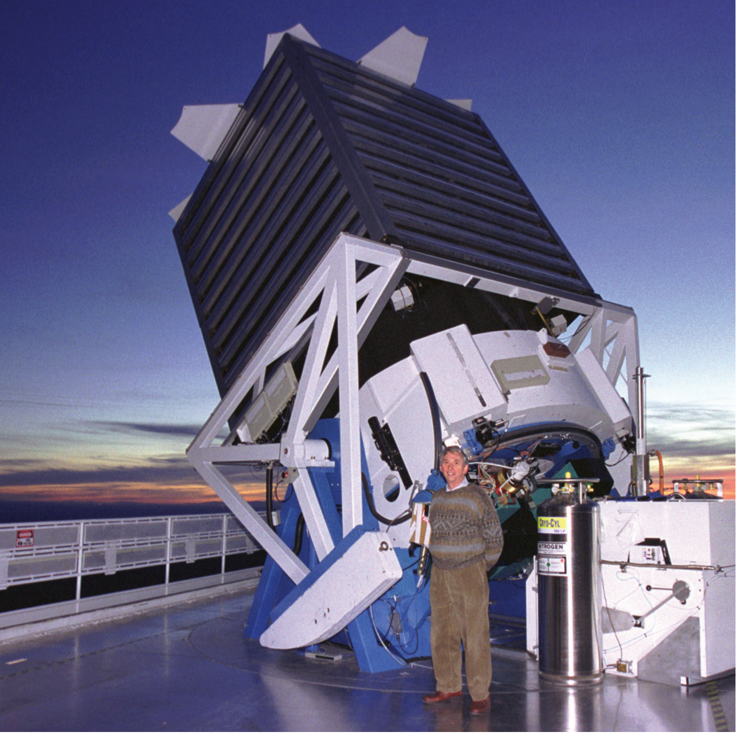


PHOTO COURTESY OF THE SLOAN DIGITAL SKY SURVEY (SDSS.ORG)

The Sloan telescope with John Peoples, former survey director.

quintessence, a dynamical fluid filling all space, and more-radical models that modify Einstein's theory of general relativity. "To begin to distinguish the various models," says Habib, "we need to reduce the overall uncertainty in theory and in observations from 10 percent to about 1 percent. This is going to be extremely difficult."

The density of dark energy is miniscule compared with the density of matter in regions like the solar system and our own galaxy. Only by observing huge volumes of space extending hundreds of millions of light-years across the sky (a light-year is 10 trillion kilometers) and billions of years back in time can astronomers hope to trace the imprint of dark energy on the dynamics of the universe.

Mapping the Universe

As part of its dark energy effort, Los Alamos has become a member of the Sloan Digital Sky Survey (http://www.sdss.org/).

Dedicated to mapping the universe, the Sloan survey has imaged more than 200 million celestial objects, and its researchers have seen back in time to when the universe was about 5 billion years old and only two-thirds of its present size. Situated at Apache Point in the Sacramento Mountains of southern New Mexico, where crystal clear nights make for ideal viewing of the distant universe, the Sloan 2.5-meter-diameter digital telescope records continuously through the night, imaging a narrow strip of sky the width of the moon as the Earth turns on its axis. The strips are then laid side by side to give a contiguous view of the quarter of the sky visible to the telescope.

"The Sloan survey was the coming of 'big science' to cosmology," comments Habib. "It's no longer a single astronomer observing the night sky, but large teams of people gathering the data and ensuring its precision. The follow-up requires state-of-the-art computing infrastructures to handle very large data sets and large-scale simulations to connect observations to theory. Los Alamos and other national laboratories provide an ideal place for this type of analysis."

Powerful computing capabilities, developed to simulate the performance of nuclear weapons in the U.S. stockpile, can be applied to the problem of simulating the cosmos. "We are also developing a unique statistical approach to minimize uncertainties in the predictions drawn from computer simulations," says Los Alamos scientist Katrin Heitmann. "It allows us to get more-accurate results with many fewer simulations and to interpolate to new models of what the universe might look like."

Los Alamos will build on an impressive track record in computational cosmology. Back in the 1990s, when theorists and observers were in strong disagreement about the dominance of dark matter, Los Alamos scientist Mike Warren used the computer to follow the expansion of the universe in one of the largest cosmology simulations ever done at that time, one based on 17 million particles of cold dark matter.

Warren's prediction about the average velocity of one galaxy relative to another was easy to check. At first, Warren's result was much higher than that reported by observers, but careful comparison showed that the observers had made an error, inadvertently removing the high-velocity galaxies of a very large nearby cluster from their published analysis. When those galaxies were included, observations agreed with simulations. Warren wears a sphinx-like smile as he quietly states, "We began to realize that the computer was becoming as important as the telescope in shaping our understanding of the universe."

Ten years later, Warren's original computer code, run on the Lab's giant supercomputers, can simulate the evolution of a billion particles in a volume 3 billion light-years on a side. It is being used by several groups to interpret the Sloan data, including the data showing huge matter-density waves with a wavelength of about 300 million light-years.

Warren's code is now one of many that predict the dark matter distribution using variable amounts of dark energy, dark matter, and normal matter and different rates of cosmic expansion. The dark matter distributions are then lit up by populating them with galaxies, and the resulting distributions of galaxies and galaxy velocities are compared with data from the surveys. The problem is that the codes don't all agree, and the observations may be plagued by systematic errors. If the fate of the universe is to be known, then astronomers, physicists, and computer wizards have their work cut out for them.

In the next 10 to 20 years, astronomers hope that complementary observations will circumvent the problem of systematic errors and lead to 99 percent overall accuracy. In the meantime Habib and colleagues hope to establish an international computational cosmology center at Los Alamos, where astronomers can analyze all the measurements and codes in a consistent way to find out whether or not the universe is undergoing unbounded acceleration.

Others, like Mottola, are using pencil and paper to search for a new idea that will fill the void between Einstein's theory of gravity and the quantum theories of nuclear and particle physics. Mottola explains, "Dark energy may be telling us that quantum fluctuations have gravitational effects at the very largest scales. This would be our first real hint from experiment at what a quantum theory of gravity should be like, and it may lead to entirely new directions in physics. For example, quantum fluctuations could change present ideas about black holes, with a dark energy repulsive core replacing the singularities of Einstein's theory. New ideas are definitely needed."

These are heady times in physics, with the biggest questions of all—what is the universe made of and how did it get here—being asked once again.

In Search of Strong Gravitational Lenses

Los Alamos is importing tens of terabytes of imaging and spectroscopic data—the entire Sloan Digital Sky Survey—with the goal of investigating gravitational lenses. A strong lens is a large mass concentration (presumably dominated by a dark matter halo) somewhere along the line of sight between the observer and a distant source that produces multiple images of the same object. More than a hundred strong lenses with split images were expected in the Sloan survey, but fewer than 20 were found. Los Alamos scientist Przemek Wozniak will lead a search through the entire Sloan data set for the missing lenses.

Why does a very massive dark matter halo act like a lens? Its gravitational pull does just what Einstein predicted: it bends the surrounding space, causing the shortest path between two points to be a curve rather than a straight line. Since light always travels the shortest path, it will bend as it travels past a dark matter halo. By causing sufficient bending, a strong lens allows the light from the source to reach the observer over multiple paths, thus creating a cosmic mirage with multiple images of the same object.

Wozniak is developing a high-speed program specially designed to search for the characteristic signature of multiple images of quasars lensed by galaxy cores. This is an excellent technique for finding dark matter and measuring its density contrast, a quantity that can be used to evaluate competing scenarios for global evolution of the universe.

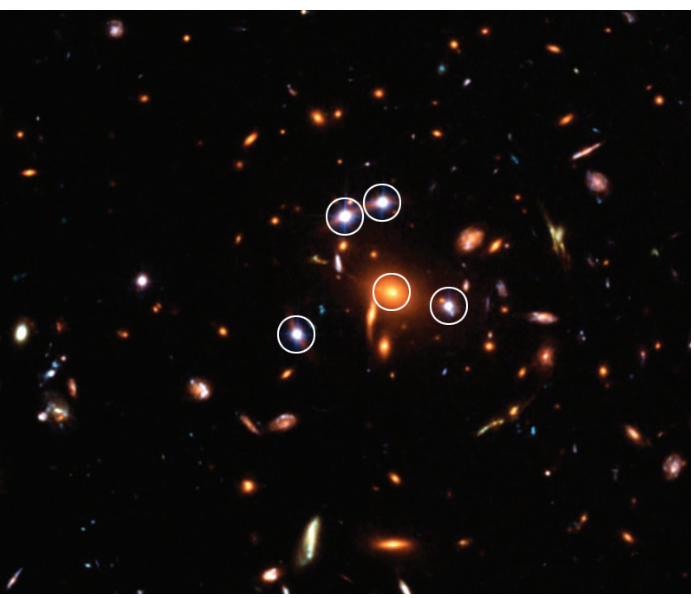


PHOTO COURTESY OF NASA, ESA, K. SHARON (TEL AVIV UNIVERSITY) AND E. OFEK (CALTECH).

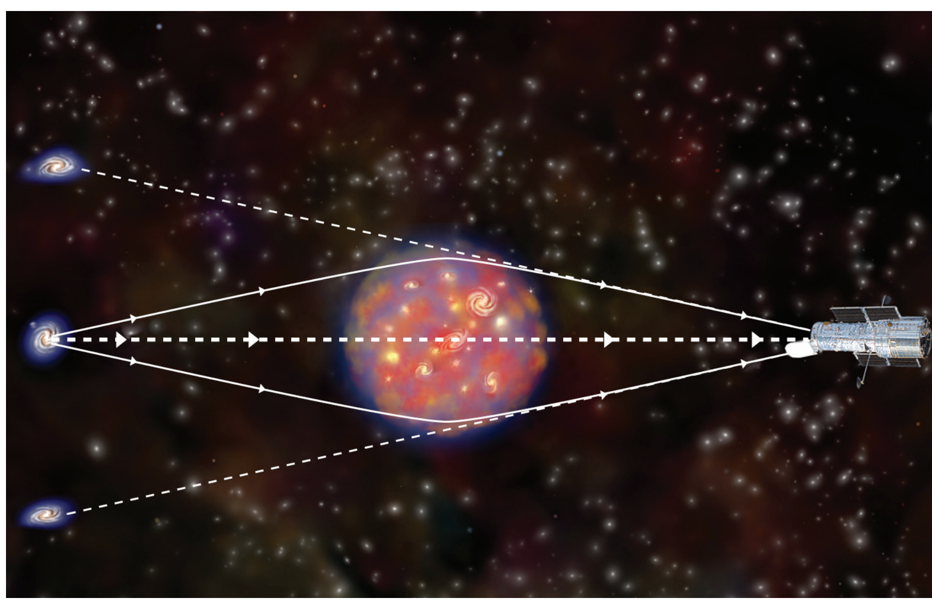


ILLUSTRATION COURTESY OF NASA/ CXC/M.WEISS.

(Left) Evidence for a dark matter halo between us and a quasar. An invisible dark matter halo acts as a gravitational lens, bending the light from the quasar and producing five quasar images (circled). (Right) Strong gravitational lensing. A dark matter halo (center) between a distant galaxy and the telescope bends the galaxy's light to create two distorted images "above" and "below" the galaxy's actual location.

THE RRW HAS THE POTENTIAL TO SIGNIFICANTLY REDUCE THE COUNTRY'S NUCLEAR STOCKPILE WHILE TRANSFORMING THE NUCLEAR WEAPONS COMPLEX INTO A LEANER, MORE RESPONSIVE ENTERPRISE.

THE RELIABLE REPLACEMENT WARHEAD
CATALYST FOR CHANGE

by Paul White

CALCULATION BY BOB WEAVER. PHOTO BY PRESLEY SALAZ.

Realistic 3-D visualizations of computer calculations help Los Alamos weapons designers understand the complicated material flow patterns that develop during nuclear detonations. In the simulation shown above, golden mesh and white marker particles are calculational aids.

BENEFITS OF RRW

STOCKPILE	• SUSTAINABLE • IMPROVED CONFIDENCE • SMALLER RESERVE STOCKPILE
NUCLEAR ENTERPRISE	• GREATER COST EFFECTIVENESS • INVIGORATED DESIGN & ENGINEERING CAPABILITY • GREATER DISMANTLEMENT CAPACITY
DEFENSE POLICY	• MORE-EFFECTIVE ASSURANCE OF ALLIES • MORE-EFFECTIVE DISSUASION AND DETERRENCE OF POTENTIAL ADVERSARIES
ARMS CONTROL	• REDUCED LIKELIHOOD OF NUCLEAR TESTING • GREATER REDUCTIONS IN TOTAL STOCKPILE

Sixty years ago, in the high desert north of Alamogordo, New Mexico, a blinding flash of light suddenly filled the early morning sky. It was "the brightest light I have ever seen. . . A new thing had just been born," recalled Isador Isaac Rabi in *Science: The Center of Culture*. The device that spawned the first manmade nuclear explosion was conceived by the brilliant minds Robert Oppenheimer had gathered at Los Alamos during World War II.

Oppenheimer's team, driven by the wartime need and the technical challenge, delivered the two distinct weapon designs whose devastating effects ended the war in the Pacific. Technical uncertainties about one, the Fat Man plutonium implosion design, were great enough that a full-scale nuclear test was needed before military use could be risked. Confidence in the other, the Little Boy uranium gun design, was high enough that the weapon (containing virtually the entire U.S. supply of uranium-235) was deployed without a nuclear test.

Today a new cadre of physicists, engineers, materials scientists, and others is giving birth to a new warhead concept—the Reliable Replacement Warhead (RRW)—with an intensity and sense of urgency that recall the early years at Los Alamos. No longer bound by the imperatives that led to the high-performance designs of the Cold War, the New Mexico RRW team is looking to a conservative design that, like Little Boy, minimizes performance uncertainties and can be deployed without nuclear testing. The RRW program would replace yesterday's high-performance designs with prudent alternatives that can be maintained with the modern tools of Stockpile Stewardship, the program launched in the early 1990s as the best approach for maintaining stockpile reliability without nuclear testing.

According to Joe Martz, the bold and enthusiastic New Mexico project lead, the RRW effort "presages a whole new way of doing business for the weapons complex, closely integrating design, engineering, supporting experiment, tooling, and manufacturing." If Little Boy and Fat Man foreshadowed the long, slow buildup of Cold War nuclear stockpiles, the RRW will be the catalyst for enabling further stockpile reductions and transforming today's nuclear complex into the leaner, more responsive infrastructure of the future.

Today's Aging Stockpile

Today's stockpile systems were designed during the superpower struggle with the Soviet Union. A driving requirement was to package more and more explosive power (yield) in ever smaller and lighter packages, whether for ballistic missile or air carrier delivery. Evolving military needs and delivery vehicle modernization often led to new requirements for warheads with different yields, weights, sizes, and other characteristics. Consequently, each warhead that was added to the nation's stockpile was of a new design, manufactured by unique processes and procedures. The entire composition of the stockpile turned over every 20 years.

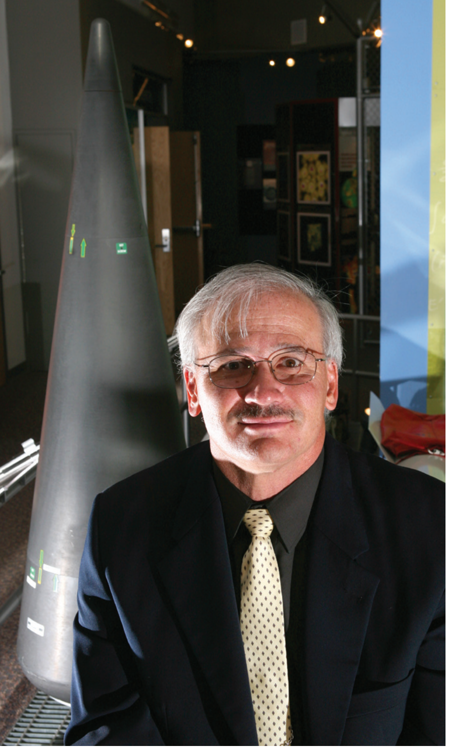
> "I am committed to achieving a credible deterrent with the lowest possible number of nuclear weapons consistent with our national security needs, including our obligations to our allies."
>
> —President George W. Bush, remarks to students and faculty at the National Defense University, May 1, 2006.

The United States, however, has not fielded a new warhead design since the early '80s. The average age of the systems now in the stockpile is 22.5 years. At least one system is more than 30 years old. This aging stockpile is being maintained with increasing difficulty using the tools of Stockpile Stewardship. Among those tools is a vital program of stockpile surveillance. Every year, physicists and engineers take representative warheads apart and scrutinize them with the thoroughness of crime scene investigators. They are learning that time is an enemy of the stockpile.

Surveillance is revealing a growing number of age-related problems, such as material failure or corrosion, that individually or cumulatively will eventually affect weapon performance. Most problems identified in stockpile surveillance are resolved without any impact on the safety, security, or reliability of stockpile weapon systems.

Joe Martz, project leader of the New Mexico RRW team, has a gift for pulling people together across disciplines and institutions. Team members are from Los Alamos and Sandia national labs.

When an assessment reveals the possibility of a serious effect on stockpile systems, there are several options, each with its own impact. For some issues it is possible to shorten the time interval for replacing limited-life components in the field, for example, tritium gas reservoirs. For other issues, establishing an exception to the ways in which the military stores or uses



John Pedicini, the Los Alamos RRW design team leader, is one of the few active Los Alamos nuclear weapons designers to have been through the whole process of designing and testing a nuclear weapon. For several decades Pedicini championed the concept of a robust weapon that could be deployed without testing.

a weapons system may be considered. For example, limits might be placed on the temperature environment to which a warhead may be exposed, or restrictions might be placed on the mechanical stresses it may experience. Sometimes it proves necessary to modify the military characteristics originally established for a system, for example, to specify a wider performance band for a militarily significant parameter, such as yield over target. If none of these options is feasible or acceptable, then the National Nuclear Security Administration (NNSA) and the Department of Defense may jointly agree to initiate a system life-extension program.

In that event, all affected warheads are returned to the production complex for remanufacture of some of their components. But such a path inevitably leads to more and more uncertainty. Many of yesterday's materials, subcomponents, and manufacturing methods cannot be duplicated today. Consequently, remanufacturing decisions are required during every life-extension program. Alternative materials and manufacturing procedures are chosen to minimize the uncertainty introduced in key performance parameters, but the cumulative uncertainty grows inexorably. In the context of the extremely tight Cold War design constraints, this growing uncertainty will eventually become unacceptable. Maintaining the legacy stockpile in this manner—through life extension but without nuclear testing—cannot indefinitely sustain confidence in our nuclear deterrent.

An RRW Stockpile for Tomorrow

There is an alternative, more sustainable path. In today's post–Cold War world, the United States can afford to relax yesterday's constraints on warhead weight, size, and other military characteristics, including—in some cases—yield. That leeway in constraints can allow a new approach that permits replacement warheads with increased performance margins.

Confidence in these greater margins is based on data from years of nuclear test experience. There is no more diligent student of that testing history than John Pedicini, the intense, highly creative leader of the Los Alamos RRW design team. Poring over the test data, Pedicini and his team of younger physicists have cataloged all of the ways that nuclear explosives can fail—the edges, or "cliffs," past which a nuclear design parameter cannot be pushed without causing the explosion to fail.

The RRW design is planted right on the middle ground of design parameters, far away from all failure-mode cliffs, which translates into a large performance margin. Consequently, designers are confident that RRW designs can be certified for deployment using the increasingly powerful computational and experimental tools of Stockpile Stewardship and without any need for nuclear testing. In other words, choosing the RRW path actually reduces the likelihood that the United States would ever have to resume nuclear testing to sustain a reliable nuclear stockpile.

The RRW program will also be a vehicle for transforming the nuclear enterprise—the sum of all the people, operations, and facilities that are needed

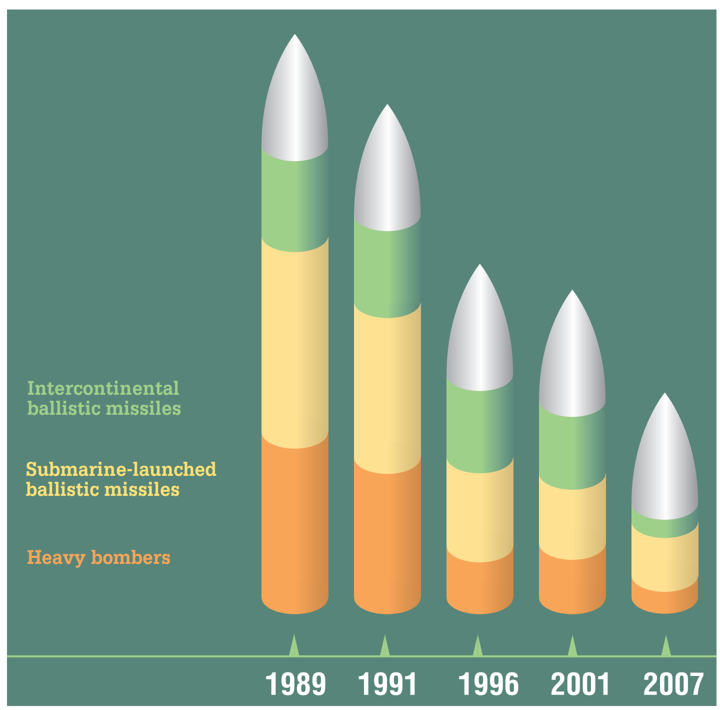
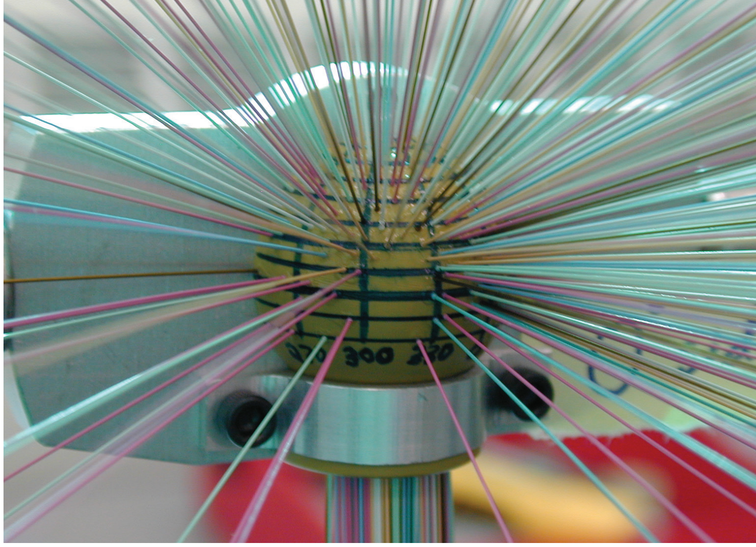


ILLUSTRATION BY JAY TRACY

In response to changing national security needs, the United States has been decreasing its nuclear weapons stockpile through unilateral actions and bilateral agreements. These reductions illustrate the U.S. commitment to Article VI of the Treaty on the Non-Proliferation of Nuclear Weapons. RRW deployment can help continue this trend.



LEFT: PHOTO BY HX-3 RIGHT: PHOTO BY MARK HOVERSON, HX-3

A non-nuclear test of the Los Alamos RRW design was performed at DARHT, the Los Alamos Dual-Axis Radiographic Hydrotest facility. X-ray pictures and other diagnostics showed that the implosion system behaved as expected.

Hundreds of wire pins extending from the central yellow pin dome are designed to generate signals upon contact with a moving surface. Those signals are used to track the implosion of material as it moves toward the center of an RRW assembly.

to produce nuclear weapons. Design engineers used modern computational methods to share details of RRW component designs with production plants in near real time. Production engineers can immediately see how components fit together and develop assembly strategies. Because RRW designs are simpler and use fewer but more-standardized parts and materials, production costs can be reduced. Enhanced intrinsic warhead safety and security simplify operations for production plants. The net result will be a nuclear enterprise that can be responsive to changes in national security requirements.

As RRW designs are developed, they can gradually replace legacy systems. Over time, it is envisioned that the stockpile will be transformed, first into a mixture of legacy and RRW systems and ultimately into an all-RRW stockpile.

With a transformed stockpile comes another important benefit—the total numbers of weapons in the nuclear stockpile can be smaller. Deployed nuclear warheads are supplemented by a reserve that serves as a hedge against two possibilities: a catastrophic technical failure of one of the nuclear systems and/or a sudden change in international circumstances. Even the reserve is larger than it might otherwise be because today the United States cannot produce the plutonium parts used in modern nuclear warheads. As an RRW stockpile becomes a reality and our production infrastructure is restored and transformed, the size of the reserve stockpile can be reduced.

Moving Ahead with RRW

The RRW didn't just emerge overnight as a preferred path for the future of the U.S. nuclear deterrent. The two nuclear design laboratories—Los Alamos and Lawrence Livermore—have worked together with NNSA and the Department of Defense to forge this new approach to sustaining the nuclear stockpile. The U.S. Congress, too, became convinced of the promise in this approach and authorized the investment of funds to make this path a reality.

Right now the two laboratories, working with Sandia National Laboratories, are competing to come up with the best possible design for the RRW. In December the Nuclear Weapons Council endorsed the RRW program as the right approach for sustaining the stockpile; the council will announce its preferred design in the near future. But that will mark just another beginning.

Making the RRW a reality will not be the work of just one laboratory. All parts of the nuclear enterprise will share the responsibility for turning the winning design concept into production reality, and all parts will work together to make the nuclear enterprise leaner and more responsive. Everyone will be involved, and the whole country will win.

Sixty years ago, the conservative, high-margin Little Boy design helped launch the original nuclear production complex and stimulated the succession of warhead designs that provided the nation's deterrent strength through the Cold War. Today, the RRW is paving the way for a transformed and leaner stockpile in support of our nation's defense requirements in an uncertain world. The RRW approach promises a stockpile that can be sustained with high confidence in its safety, reliability, and effectiveness for as long as the nation requires.

Paul White is the director of the Los Alamos National Security Office.

If nuclear is one answer to the world's increasing demand for energy, how does the world deal with the potential proliferation and waste issues and at the same time satisfy individual national interests?

Partnership. A global partnership.

Expanding Nuclear Energy the Right Way

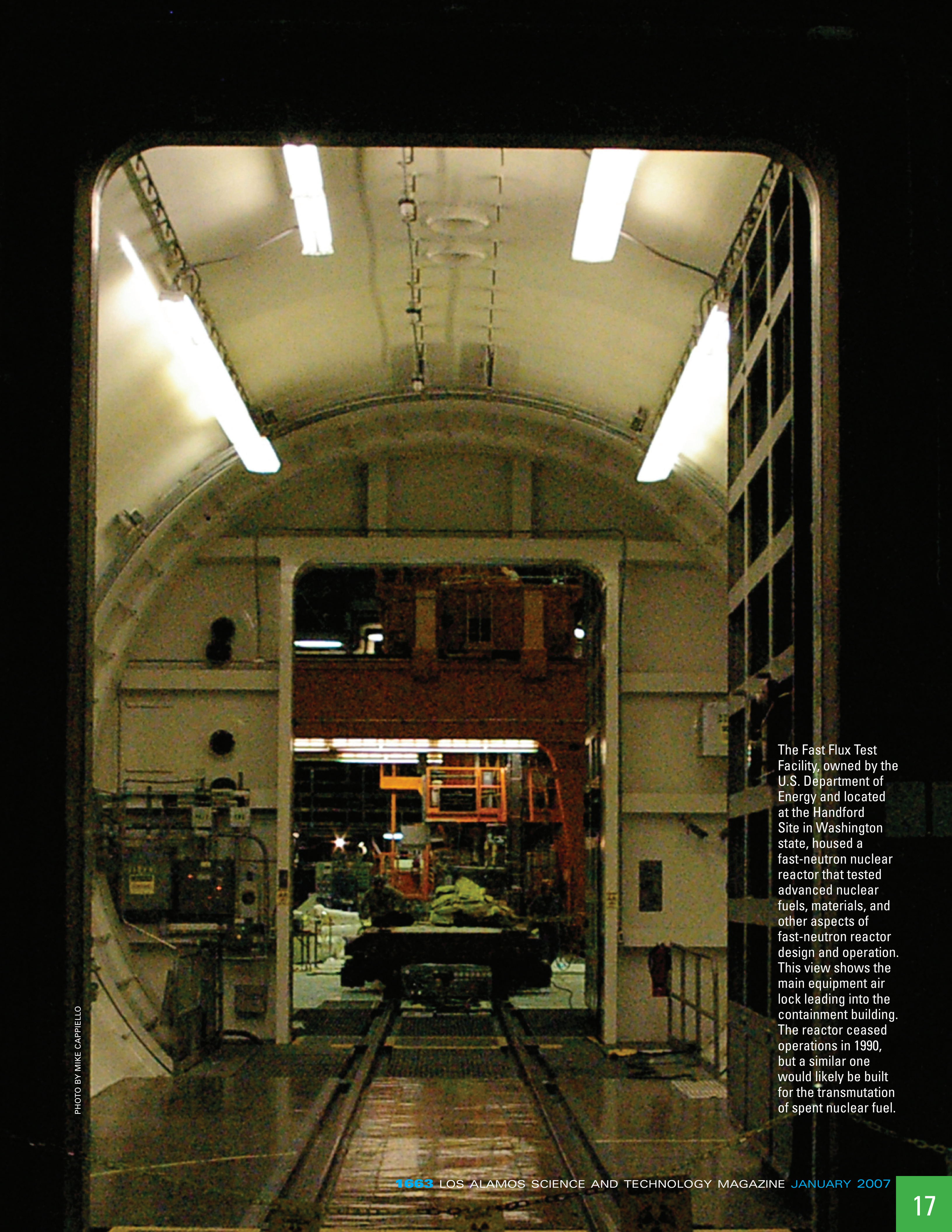
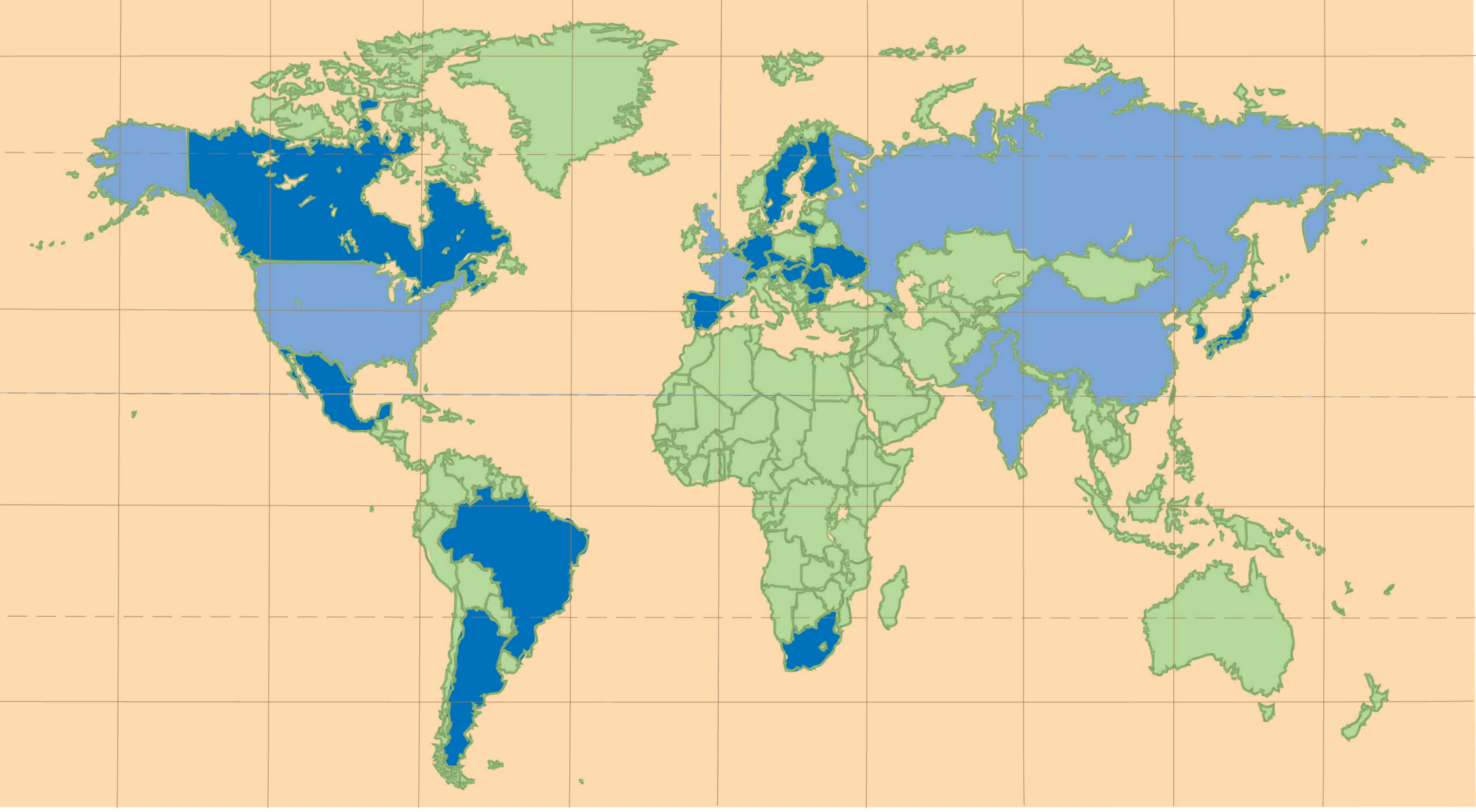


PHOTO BY MIKE CAPPIELLO

The Fast Flux Test Facility, owned by the U.S. Department of Energy and located at the Handford Site in Washington state, housed a fast-neutron nuclear reactor that tested advanced nuclear fuels, materials, and other aspects of fast-neutron reactor design and operation. This view shows the main equipment air lock leading into the containment building. The reactor ceased operations in 1990, but a similar one would likely be built for the transmutation of spent nuclear fuel.



Global Nuclear Energy Partnership

Vietnam doesn't have an extensive power grid, so the country would like to use small-scale nuclear reactors to feed electricity locally to cities and villages. The Vietnamese, however, don't have the facilities to enrich uranium or contend with the radioactive spent fuel and so are hesitant to invest in reactors.

Japan and France, lacking coal and oil resources, view nuclear energy as vital to their energy security. They have invested heavily in large-scale nuclear power plants and recycle their spent fuel to get the most out of it.

China will need enormous amounts of electricity to power its burgeoning economy. After considering the economic and environmental tradeoffs, it has decided on an 8-fold expansion of its nuclear capacity by 2020, with a 40-fold increase planned by 2050.

Russia intends to have nuclear energy provide 25 percent of its electricity by 2030 and has aggressive plans to establish an international uranium enrichment facility, to build a reprocessing plant to recycle spent fuel, and to market small modular reactors to developing countries.

The United States, the country with the most nuclear power reactors in the world (103), has not built a new plant in three decades. It has a nuclear power infrastructure devoted to the safe and efficient operation of its water-cooled reactors but does not recycle spent nuclear fuel, of which it has accumulated about 50,000 metric tons. It is looking to expand nuclear energy as a means of obtaining clean electricity while reducing its dependence on fossil fuels and is expected to review 30 or more new power reactors for license.

Australia has abundant uranium ore and is poised to start a uranium enrichment program. Canada would like to sell advanced reactors to the world. India has plans to construct some 25 new nuclear plants, while Poland and Indonesia are exploring going nuclear. Iran is enriching uranium, a capability that can readily be adapted to producing material for nuclear weapons. North Korea, which has extracted plutonium from spent fuel, has already moved in that direction.

Thirty nations, shown in blue and light blue, have commercial nuclear reactors that today supply approximately 16 percent of the world's electricity.

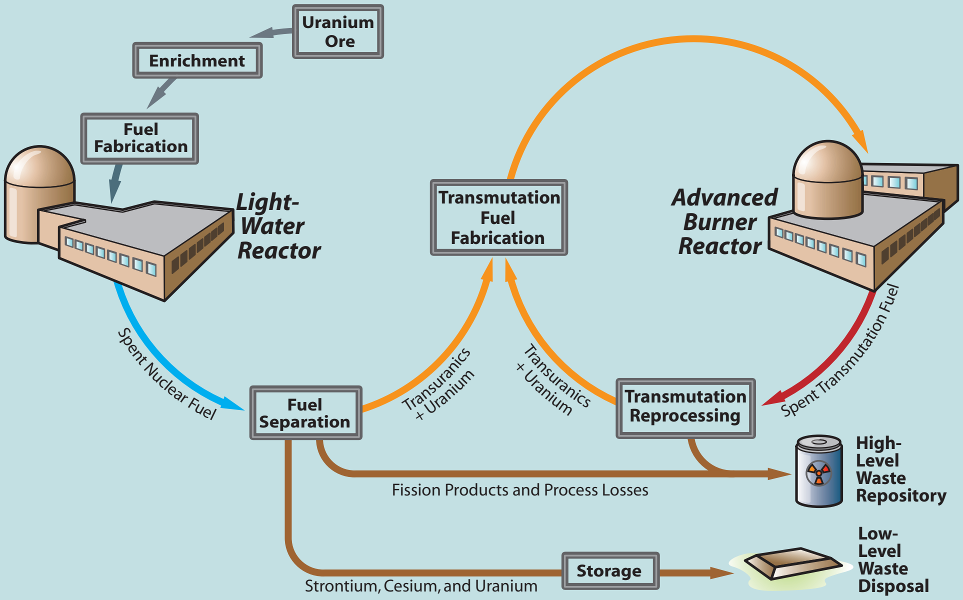
Get the picture? Faced with dwindling oil reserves and global climate change brought on by fossil-fuel emissions, the world is again looking at nuclear energy. But each nation has a different perspective on this complex energy resource, a unique view that attempts to balance political needs with economic and environmental concerns. If nuclear is one answer to the world's increasing demand for energy, how does the world deal with the potential proliferation and waste issues and at the same time satisfy individual national interests?

A Global Initiative

"We recognize that to realize significant increases in nuclear power," says Dennis Spurgeon, the Department of Energy's Assistant Secretary for Nuclear Energy, "we need a new framework for the utilization of nuclear energy."

That new framework is the Global Nuclear Energy Partnership, or GNEP (pronounced GEE-nep), which the Bush Administration formally unveiled in February 2006. By fostering international cooperation—global partnerships—GNEP hopes to greatly expand the use of nuclear energy around the world while addressing both the proliferation and waste issues.

GNEP plans to reduce nuclear waste through an advanced fuel cycle that recycles spent uranium fuel and reprocesses it into a new type of "transmutation" fuel that would be burned in advanced burner reactors. (See "Advancing the Fuel Cycle.") The result would be a significantly smaller and more easily managed nuclear-waste stream.



Advancing the Fuel Cycle

Nuclear energy is released when a uranium nucleus absorbs a neutron and fissions into two pieces (fission products) plus two or more neutrons. If the neutrons go on to fission more uranium fuel, a chain reaction can develop—the additional fissions release more neutrons, which leads to even more fissions, and so on. A nuclear reactor is designed to sustain a controlled chain reaction and produce heat that can be used to generate electricity.

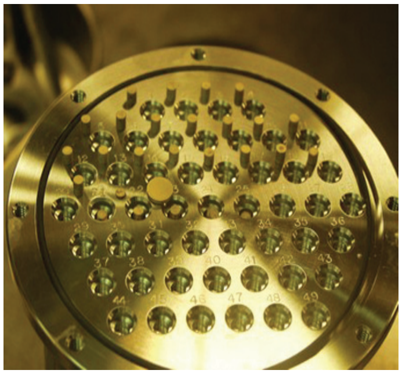
Most commercial nuclear reactors—so-called light-water reactors—use low-energy neutrons to fission the uranium isotope U-235. But the concentration of U-235 in natural uranium ore is a mere 0.7 percent, the rest being the isotope U-238, which is not fissioned by low-energy neutrons. As a result, uranium ore must be enriched to about 5 percent U-235 before it is turned into fuel. As this fuel fissions, or "burns," in the reactor, the U-235 concentration drops. When it drops too low, the fuel is spent and must be removed.

The spent fuel contains U-235 and lots of U-238 but also small amounts of plutonium, neptunium, americium, and curium—"transuranic" elements that are created by neutron capture reactions with the fuel. The uranium and transuranics are radioactive for tens of thousands to millions of years and therefore are a long-term disposal challenge. The spent fuel also contains the intensely radioactive fission products that decay to stable elements within a few hundred to a few thousand years.

In the United States, the spent fuel is simply stored, awaiting final burial in a high-level waste repository such as the one proposed for Yucca Mountain in Nevada. Given the rate at which spent fuel has been generated, the repository's legislated capacity would be reached by 2013, necessitating a new Yucca Mountain–sized repository every 30 years.

GNEP would promote an advanced fuel cycle, wherein the uranium and the transuranics would be recycled. The spent nuclear fuel would be separated into uranium, transuranics, strontium, cesium, and fission-product streams. (Plutonium would never be isolated as it is in traditional reprocessing methods.) The uranium would be either stored or recycled (re-enriched and converted into new fuel), while the strontium and cesium would be stored until their ultimate disposal in a low-level waste facility. The transuranics would be mixed with uranium and fabricated into a "transmutation" fuel that would be burned using high-energy (fast) neutrons in an advanced burner reactor. The use of fast neutrons results in a net loss (rather than creation) of transuranics. The spent transmutation fuel would also be recycled into new fuel.

This advanced recycling extracts more energy from the fuel and significantly reduces the volume of waste that gets sent to a high-level waste repository. It also greatly eases the long-term storage requirements of the repository because the waste is primarily the short-lived fission products.



Transuranic fuel pellets, standing on a test port, are typical of the materials that would be tested in the Materials Test Station and test reactors. LOS ALAMOS ARCHIVE

Proliferation concerns would be addressed by implementing an integrated program that includes the development of international fuel-leasing arrangements. As an incentive for a country to forgo the development and implementation of fuel cycle activities (uranium enrichment and the reprocessing of spent fuel—the two processes that can produce weapons-grade nuclear material), the country would be guaranteed fresh nuclear fuel from a supplier, who would then take the spent fuel back.

Furthermore, all GNEP facilities—the reactors, plus enrichment and recycling plants—could be designed to facilitate monitoring by the International Atomic Energy Agency (IAEA) through safeguards agreements. Specific features would be incorporated directly into the facilities to make them more intrinsically resistant to the diversion of nuclear materials.

The Bush Administration has requested $250 million to fund GNEP in the 2007 fiscal year, mostly to develop (at an engineering scale) the technologies needed to develop the advanced fuel cycle but also to help foster international partnerships. For example, researchers have little experience in the fabrication of transmutation fuels. While the United States is performing fundamental research to develop the technology, it is also establishing collaborations with other nations to accelerate the process.

Partnership will be of equal importance in designing the advanced burner reactor (a liquid-metal-cooled, fast-neutron reactor). Although the technology is for the most part mature (several prototype liquid-metal-cooled reactors are already in operation in other countries), the burning of transmutation fuel in the reactor needs demonstration. The transmutation fuel and the structures that contain them undergo physical changes within the high-radiation, high-temperature reactor environment, so their overall behavior and performance are unknown. To anticipate all effects prior to designing and building the reactor, GNEP will use a significant computer modeling and simulation effort supported by small-scale experimental work.

Los Alamos Plays Its Part

Los Alamos has years of reactor modeling experience dating back to the 1970s and '80s with the pioneering TRAC code—the first computer code capable of realistic reactor safety analysis—and up to the current Advanced Simulation and Computing program and associated high-performance supercomputing capabilities. Using existing capabilities as a basis, Los Alamos will perform multi-dimensional modeling and simulation of an advanced fast-neutron reactor that will span a dramatic range of physical scales, from the microscale investigation of the fuel cladding materials to the macroscale modeling of the entire facility.

GNEP program manager Mike Cappiello is leading the Los Alamos effort to develop the technologies for advanced fuel recycling.

In addition, Monte Carlo analytical techniques that were developed at Los Alamos will be used to predict the type and amount of radiation emitted by the spent fuel—the so-called radiation signature. By comparing a calculated signature with a measured result, the IAEA is in a position to know if a user is being honest with regard to its fuel inventory.

But fuel and material behaviors cannot be understood by modeling and simulation alone. The new Materials Test Station, proposed for the Los Alamos Neutron Science Center, will expose candidate fuels and cladding materials to copious amounts of fast neutrons that have nearly the same energy spectrum as that of the proposed reactor. Says GNEP program manager Mike Cappiello, "The Materials Test Station will be the only facility in the United States capable of mimicking the extreme conditions found in the advanced burner reactor."

To understand how to fabricate robust transmutation fuel, Los Alamos is using the unique resources in its Plutonium Facility and Materials Science Laboratory to develop advanced ceramic fuels. After being tested on a small number of samples, the same processes will be scaled up to higher volumes, using safe remote techniques in "hot cells" at the

Laboratory's Chemistry and Metallurgy Research facility.

Los Alamos chemists will also explore advanced chemical separation processes specially designed to implement fuel cycling and address waste management issues.

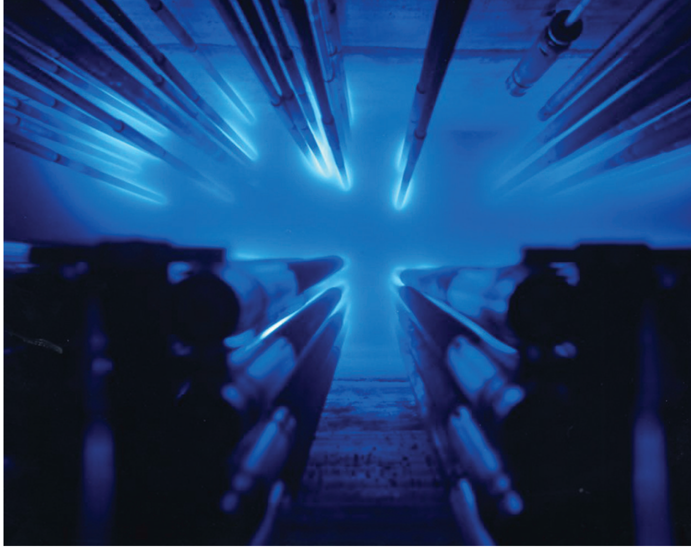
The Laboratory recently marked the 40th anniversary of the U.S. safeguards program, which was started by Los Alamos' Robert Keepin in recognition of the need to develop methods to secure, track, and account for nuclear materials. Los Alamos has continued to be the leader in safeguards systems and technology development ever since—and looks forward to applying these capabilities to the GNEP initiative.

Finally, the Laboratory can lead the nation in establishing technical working relationships with nuclear research labs around the world, as it did with Russian labs after the breakup of the Soviet Union in 1991. Los Alamos worked in partnership with the Russians to enhance the security of their nuclear facilities, installing first physical protection systems and then sophisticated electronic eyes that monitor nuclear materials and track their movements.

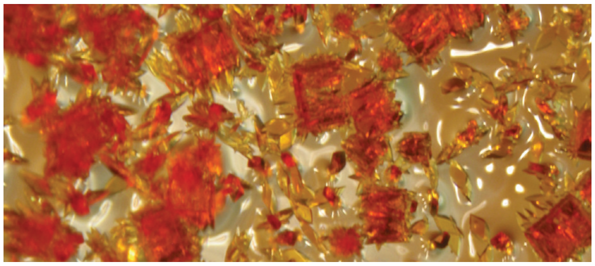
Richard Wallace, the Los Alamos project leader for International Safeguards, is enthusiastic about the possibilities of working cooperatively with Russia and other countries to resolve some of the remaining technical issues in a GNEP-type advanced fuel cycle and to find creative solutions to the international engagement issues. "Through the Department of Energy's program for Materials Protection, Control and Accounting, or MPC&A, we've been able to build a tremendous relationship with the Russians," says Wallace. "We know the people and can work together to achieve results." The Russian cooperation programs could be expanded under GNEP as part of its broader international partnerships.

Similarly, Japan will likely be a key partner in the GNEP initiative, as the country already has a very sophisticated nuclear power industry and is constructing a major reprocessing facility. Los Alamos worked closely with the U.S. and Japanese governments, industry experts, and the IAEA to support the design and implementation of a state-of-the-art safeguards system for the recycling plant at Rokosho. The collaboration illustrated the importance of incorporating monitoring systems into the facility design— a practice that undoubtedly will be followed for future GNEP facilities.

The expansion of nuclear energy is a global issue, which is why global partnerships are the foundation of GNEP's long-term vision and innovative political and technical agenda. Many nations, including Russia, France, and Japan, seem to agree with GNEP's goals and philosophy. In an energy-hungry world, everyone sees the advantages of getting nuclear "right."



Blue Cherenkov light, generated by radioactive emissions, illuminates spent fuel held in temporary storage in a water tank. PHOTO COURTESY OF ATOMIC ENERGY OF CANADA LIMITED (AECL)



Uranium crystals extracted from spent fuel by an innovative carbonate extraction method being developed at Los Alamos by Wolfgang Runde and Gordon Jarvinen. PHOTO BY WOLFGANG RUNDE

Radiation-proof hot cells in the Chemistry and Metallurgy Research facility will be used to develop the techniques to remotely fabricate transmutation fuel. LOS ALAMOS ARCHIVE

DIALOGUE

Taking the Long View

Vic Reis and Sig Hecker Talk about GNEP

Victor Reis, senior advisor to the Department of Energy, visited Los Alamos to interest the technical staff in the Global Nuclear Energy Partnership (GNEP), a framework proposed by the United States to facilitate the safe, secure, and economic expansion of nuclear energy around the globe. Reis and former Laboratory Director Siegfried Hecker, now a visiting professor at Stanford University and an advisor on cooperative threat reduction, sat down with 1663 *and shared their vision.*

1663: What does the United States want to accomplish with the Global Nuclear Energy Partnership?

Reis: There's a growing consensus around the world that nuclear power can solve concerns about greenhouse gases. At the same time, we need a nuclear nonproliferation regime that is rigorous and will stand the test of time. The GNEP initiative hopes to address both concerns by leading the world toward a new type of nuclear fuel cycle, one in which we recycle and burn almost all the nuclear fuel. The current practice in the United States is to simply store spent fuel after it has passed once through a reactor in order to avoid the proliferation risk of separating out plutonium during recycling. The advanced fuel cycle promoted by GNEP has ways around that risk.

Hecker: With GNEP, you are talking about long-term goals that must be sustained through many administrations. One approach is to build strong international partnerships. We did that with the Russians in the nuclear nonproliferation business. We developed close working relationships on the technical problems of safeguarding nuclear materials.

Reis: Interestingly enough, President Bush came at the GNEP initiative from the partnership perspective. Nuclear issues come up regularly in discussions with Russian President Vladimir Putin and other heads of state, and in some sense we're using nuclear energy as a way of fostering international partnerships.

1663: How do you get other nations interested in GNEP?

Reis: First you have to understand each country's needs. Japan, for example, imports all but 3 or 4 percent of its fuel and is concerned about continuing supplies. Nuclear is attractive to them because you have to import relatively little fuel.

Hecker: Pound for pound, nuclear is a factor of a million higher in energy content than fossil fuel. That's the real beauty of nuclear. A little goes a long way.

Reis: Right. And once you understand a country's needs, you can ask, "How do all countries who need nuclear energy get to the same place in terms of energy sustainability and security in 50 years, even though we are starting from different places?" A nuclear reactor lasts for 50 years, so that is the relevant time frame. The idea is you don't force anybody to join GNEP by any treaty. You try to make it economically and politically in their best interests.

1663: How would you characterize the U.S. perspective in this?

Reis: We are the biggest producer of nuclear power in the world. We have over 100 reactors providing 20 percent of our energy, but we haven't ordered any new reactors for 30 years. We also have a very heavy political problem with respect to burying the waste at the Yucca Mountain site. On the other hand, the NRC [Nuclear Regulatory Commission] is making plans to license up to 30 new nuclear reactors over the next 4 or 5 years.

1663: Given that our nuclear industry has been relatively dormant, and we don't recycle our spent fuel, what does the United States bring to this partnership?

Reis: We bring a lot of intellectual capability, particularly in our national laboratories and universities. We have an extraordinary ability to do computer modeling and simulation, and a number of folks believe that modeling can help us develop advanced technologies for recycling nuclear fuel and modernizing the whole way we do nuclear power. The national laboratories can play a major role in the modeling effort.

We also have in place a major research program that fits right in with GNEP. It supports research in advanced chemical separations, the design of advanced burner reactors that can burn plutonium and other transuranics [elements heavier than uranium], and the development of the new fuels that would go into those burners. In addition, we are working with France and Japan on fuel development, safeguards technology, and reactor design and plan to extend those collaborations to Russia and others.

Hecker: Another key factor is the leadership the United States brings in the nonproliferation arena. Our example can either limit the acceptance of nuclear power worldwide or enhance it. The mere fact that the United States is heading towards recycling, and the fact that we believe nuclear power to be important, not just for us but globally, makes it easier for advanced nuclear countries to work with us and helps non-nuclear countries to participate.

1663: Are the non-nuclear countries interested in participating?

Reis: We're working on it. I see three stages to building partnership. The first is to understand what you get by being a partner. The second is what Sig understands so well, cooperating on the technical level, and there we have to realize that different countries really do bring something to the table. Again the laboratories can play a very strong role here because intellectual property rights are not their primary motivator.

1663: Right, the laboratories focus more on scientific exchange.

Reis: Yes, and it's more than just sharing the science. It's the political benefit of working together and getting to know each other. Many nuclear scientists and engineers become leaders in their countries, especially in the less-developed countries, and having grown up with technical peers in other nations, they trust the value of cooperation.

The third stage is this whole idea of international fuel leasing, where certain states supply the fuel and other states use it and return the spent fuel. That's going to be a little longer in coming, but a start on that is setting up fuel banks. Secretary of Energy Sam Bodman has suggested that we have 17 tons of excess weapons-grade uranium that we could donate to a fuel bank as a guarantee to the IAEA member countries. It would be a global bank, like a strategic petroleum reserve.

Hecker: It's interesting that in the nonproliferation treaty, all the countries could build whatever part of the fuel cycle they wanted as long as they submitted to international inspections and played by the rules. In GNEP, the deal is different.

Reis: Right. GNEP will try to develop both a political approach (international fuel leasing) and a technical approach to the proliferation problem. For example, GNEP proposes to integrate materials safeguards and nonproliferation measures right into the design of each new power plant so that it will become obvious if a GNEP partner state breaks its agreements.

We recently tested our ideas in a pilot study with the University of Chicago. We asked them to consider how they would respond to a call from the Energy Ministry of Poland asking, "We've heard about GNEP. What should we do?" There are a lot of Poles and a lot of cultural sympathy at University of Chicago, so I thought they would answer from the Polish perspective.

What they did was to hold a conference in Poland on that very question. And subsequently, the president of Poland said, "We're going to go into the nuclear business." They want to become a partner state in GNEP and buy a nuclear reactor. They don't want to be dependent on Russia for their energy. They want a certain degree of independence.

Hecker: So Poland was a test case for the idea of user states, who get a reactor but are glad they don't have to bother with the rest of the fuel cycle—they can leave that to the advanced nuclear states.

1663: What about countries like Iran and North Korea? What would be their incentive to participate?

Reis: Well, we didn't propose GNEP to solve the North Korean and Iranian problems. The idea was to avoid future situations.

But it's important to realize that GNEP is not saying "no." We want everybody to have nuclear power, but we want them to play by the rules. Nuclear power is for nuclear power. It's not a way of getting into the nuclear weapons business. Along those lines, the Russians are now offering to help Iran build reactors and provide them with fuel as long as the Iranians agree not to build a uranium enrichment plant.

1663: Are all the advanced nuclear countries on board with GNEP?

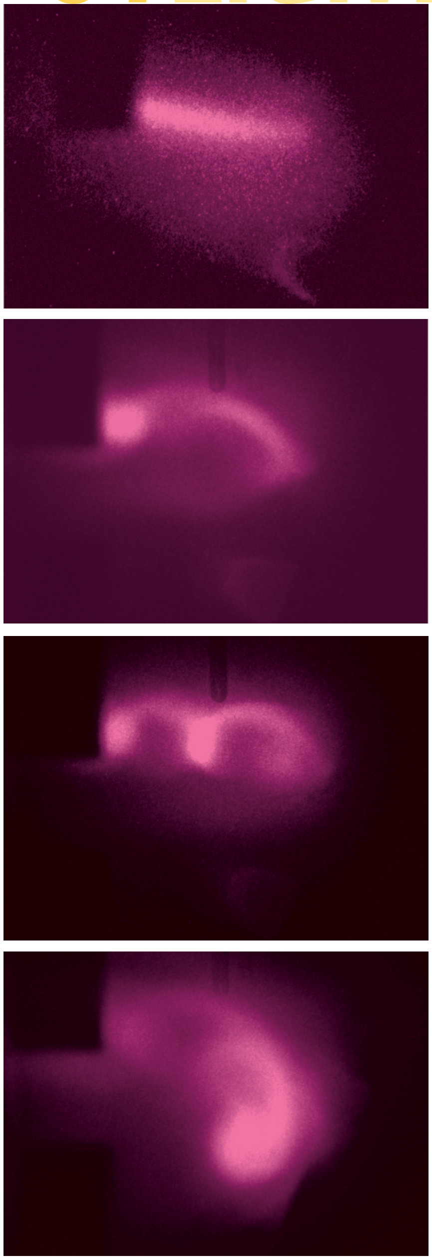
Reis: They are coming around. French President Jacques Chirac had originally said that France was going into fast reactors, primarily for breeding plutonium from uranium fuel, in the 2050 time frame. Now they [the French] are saying, "Let's start on a fast reactor that we could use either for a breeder or a burner by the year 2020." That is about the time the United States plans to have its first advanced burner reactor go online.

1663: Bright young people might be reluctant to enter these areas if they have to wait 20 years to see a product.

Reis: Right, this is a slow process, but your perspective changes as you get older. I got interested in this problem at age 65 or so, and by then I could remember 50 years back [laughter]. In my case I also have a lot of grandchildren, and I often project forward 50 years to what they might have to face in terms of climate and energy.

1663: So you've really personalized this issue.

Reis: Absolutely. But almost everybody who gets involved responds to GNEP personally—as a way to make an impact around the world.



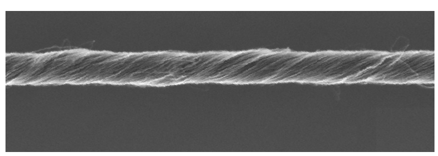
Laboratory-generated plasma evolves from flux rope to mini helix. PHOTO FROM THOMAS INTRATOR, P-24

Roping in Magnetic Fields

At the Sun's edge, in a region called the heliosphere, magnetic fields and electrical currents constantly align and twist themselves in massive 3-D structures called "magnetic flux ropes." These high-tension ropes are unstable and tend to kink and relax into helical configurations (through what theorists call the kink instability). Occasionally, a rope end—which was previously "tied" to the Sun's surface—breaks loose, ejecting electrically charged gas called plasma and producing solar flares that can wreak havoc with everything from satellites to electrical power grids.

Once observed only in places like the Sun's surface, flux ropes are now being created by Los Alamos scientists in the laboratory, making it possible to tie experimental data to prior theoretical analyses. As reported in the July 7, 2006, *Physical Review Letters*, a small plasma gun shoots plasma into a vacuum. The plasma then flows along an externally produced magnetic field to form plasma-current filaments, or flexible wires composed of plasma. These "mini flux ropes" are photographed and studied with probe measurements as they wind helically around an imaginary central axis (see photo sequence at left).

This close-up study can shed light on the effects of flux ropes in everything from the Earth's magnetosphere to the giant astrophysical jets and radio lobes associated with active galaxies throughout the universe. According to Los Alamos experimentalist Thomas Intrator, "The more we learn in the laboratory, the more we'll know about how solar flares are produced and how the energy locked up in magnetic fields affects the large-scale structure of the universe."



A carbon-nanotube fiber less than 3 micrometers in diameter. PHOTO FROM Y.T. ZHU, MPA-STC

Carbon Nanotubes Do the Twist

What happens when you take a one-atom-thick sheet of carbon atoms and roll it up into a tube? You get a single-walled carbon nanotube that is likely the strongest material ever made by man. But due to nanotubes' extraordinarily small size—typically only a few nanometers in diameter (about one 10-thousandth the diameter of a human hair) and on the order of 10 micrometers long—their projected uses were primarily limited to new types of nano-scale electronics, such as micro electric motors or ultra-small wires, or else to biological or chemical sensors.

A new twist on carbon nanotubes began in 2004, when a team led by Yuntian T. Zhu of Los Alamos discovered how to grow longer nanotubes, thus opening the door to new uses. Now Zhu and his team are spinning 1-millimeter-long, double-walled carbon nanotubes into tough fibers that pound for pound are 100 times stronger than steel. These super-strong, lightweight fibers could be ideal for many commercial applications, such as aircraft materials, body armor, automobile parts, prosthetic devices, or sports and recreation products. They might even be used to create a cable system for a space elevator and transport people and supplies from the Earth to a tethered space platform.

Los Alamos has licensed its carbon nanotube technology to a new commercial partner, Seattle-based CNT Technologies, Inc. The company plans to be producing one kilogram of fibers per day within the next six months.

DOCUMENT FROM ECLECTICOLLECTIONS

Is This a Real Rembrandt?

For years, x-rays have been used to help uncover the breaks in our bones and the holes in our teeth. Now these penetrating rays are helping museum conservators confirm the authenticity of masterworks of art.

Micro x-ray fluorescence (MXRF) uses an optic to focus x-rays onto a sample and excite its atoms, which then emit their own characteristic x-rays. Researchers can collect the emitted x-rays with a detector and construct a 2-D map of the elements in the sample. Now George Havrilla and co-workers at Los Alamos have turned MXRF into a 3-D mapping tool. By adding a focusing element to the detector, they can collect x-rays only from within the small "probe volume" defined by the intersection of the source and detector focal regions (a "confocal" arrangement).

Due to the penetrating nature of x-rays, the probe volume can be positioned anywhere within the sample's interior. Confocal MXRF can therefore probe the different layers of paint on a purported masterpiece and determine provenance based on the elemental composition of each layer, thereby confirming the actual pigments used. The technique is nondestructive, so the probing could be done in the middle of the painting. The conventional method involves removing and analyzing a speck of paint. To avoid harming the painting, the speck is taken from the painting's edge, which may not be representative of the central portion of the artwork.

Many conservators expressed great interest in Havrilla's technique when he presented it in Los Angeles at a Getty Museum conservation workshop this past summer.

All Aboard!

Hydrogen tops the list of promising carbon-free fuels for cars, but one of the biggest obstacles to its use is the difficulty of storing enough fuel on board to avoid frequent stops at a "hydrogen station."

How best to achieve the benchmark of 300 miles of travel without refueling? It may be to use the lightweight compound ammonia-borane to carry the hydrogen. With hydrogen accounting for almost 20 percent of its weight, this stable, non-flammable compound is one of the highest-capacity materials for storing hydrogen. In a car, the introduction of a chemical catalyst would release the hydrogen as needed, thus avoiding on-board storage of large quantities of flammable hydrogen gas. When the ammonia-borane fuel is depleted of hydrogen, it would be regenerated at a hydrogen station through a reverse reaction.

Known hydrogen-releasing catalysts are typically metals or their complexes, but they may complicate the reverse reaction. In a recent discovery, Frances Stephens and Tom Baker of Los Alamos National Lab, in collaboration with computational chemists at the University of Alabama, have shown that non-metal acids can catalyze the release of hydrogen. Their analysis has also shown that a similar mechanism of acid-initiated hydrogen release likely applies to ammonia-borane in the solid state and in ionic liquid solvents, forms that could be useful for transportation.

Within the U.S. Department of Energy's Chemical Hydrogen Storage Center of Excellence, work is proceeding to analyze the entire fuel cycle for ammonia-borane, including generation, use, and reuse. Engineering and economic evaluation of the utility of this novel transportation fuel will be conducted by the center over the next few years.

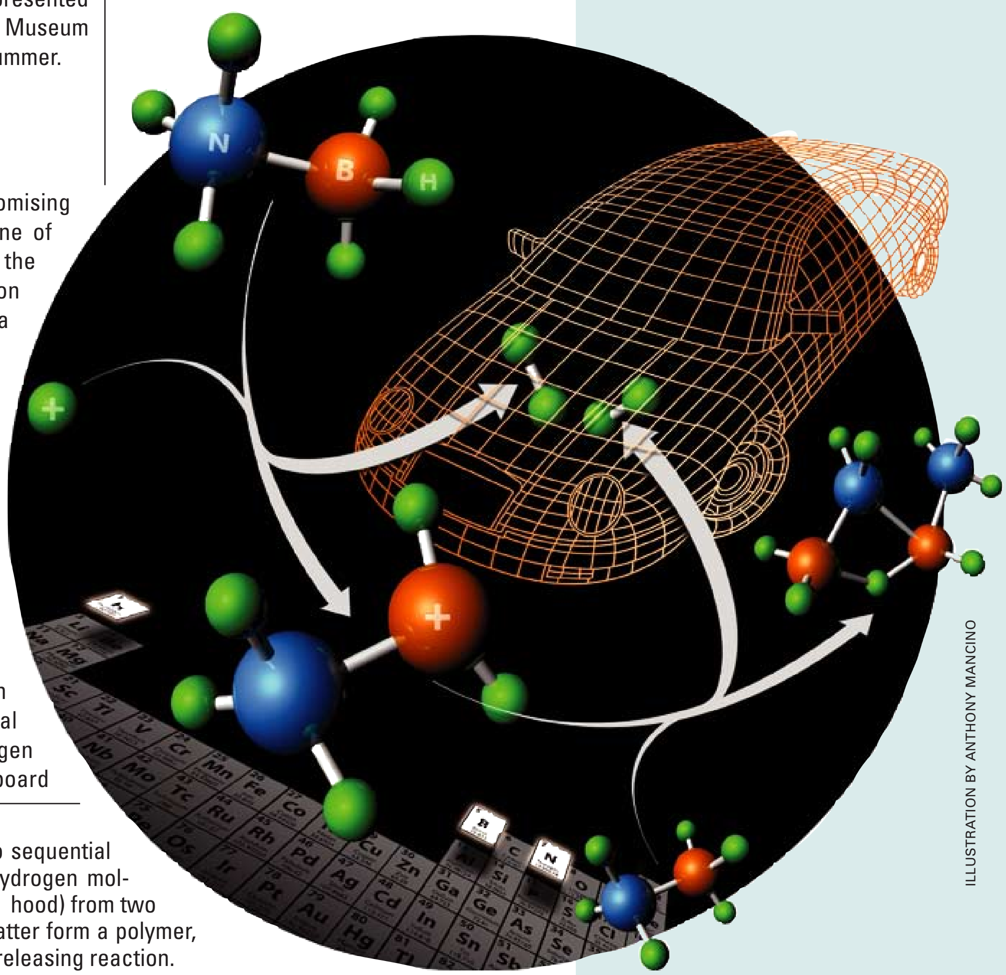


ILLUSTRATION BY ANTHONY MANCINO

From upper left to lower right, two sequential chemical reactions release two hydrogen molecules (green molecules under the hood) from two ammonia-borane molecules. The latter form a polymer, which can continue the hydrogen-releasing reaction.

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